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AMBIENT TEMPERATURE CHANGES AND THE IMPACT TO TIME MEASUREMENT ERROR

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Abstract. Measurements in Geodetic Astronomy are mainly outdoors and performed during a night, when the temperature often decreases very quickly. The time-keeping during a measuring session is provided by collecting UTC time ticks from a GPS receiver and transferring them to a laptop computer. An interrupt handler routine processes received UTC impulses in real-time and calculates the clock parameters. The characteristics of the computer quartz clock are influenced by temperature changes of the environment. We exposed the laptop to different environmental temperature conditions, and calculate the clock parameters for each environmental model. The results show that the laptop used for time-keeping in outdoor measurements should be kept in a stable temperature environment, at temperatures near 20°C

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1. INTRODUCTION

A key issue for astro-geodetic field measurements is the time-keeping. The transit times of observed stars are measured by a quartz clock, nevertheless is it provided as a separate device, or incorporated within a laptop running the observation programme. The quartz oscillators characteristics depend, among the other factors, on temperature changes. Since the determinations of astronomical coordinates are performed outdoors, the quartz is exposed to ambient conditions that can change rapidly in time.

2. BACKGROUND AND METHODS

2. 1. THEORY OF QUARTZ

Piezo-electricity is the primary property of a crystal which makes it usable as a resonator. It is an electric polarization that can be produced by different forms of strain (bending, shear, torsion, tension, and compression). Most of the physical properties of a crystal are anisotropic. That is why changes during the growth of the crystal result in crystal imperfections. The desired result of the crystal and its associated oscillator circuit is a precise frequency (HP, 1997-1).

The frequency of the oscillator will change due to the following factors: temperature effects, long-term time change (aging), short-term time change (time domain

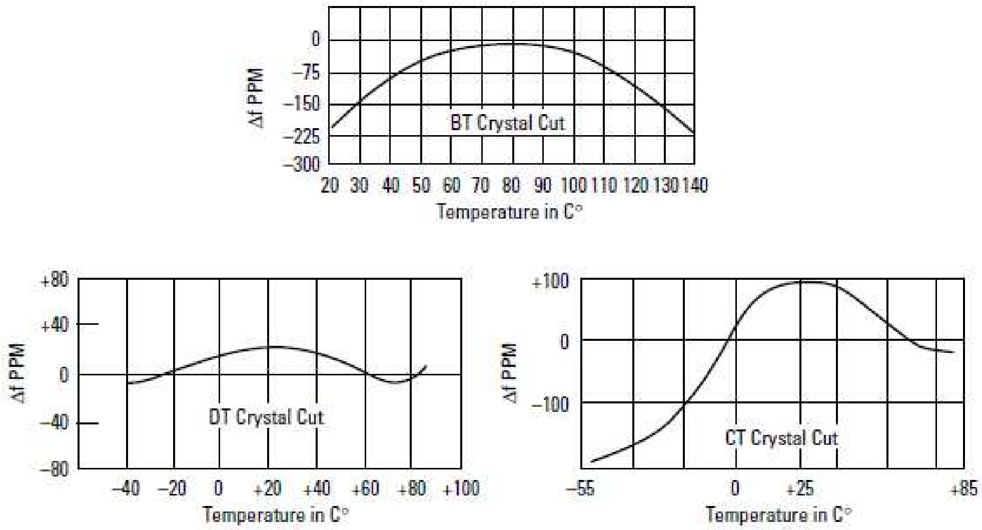

Figure 1: The temperature dependence of various crystal cuts (HP 1997-1).

stability), drive energy, gravity, shock, vibration, electromagnetic interference, and retrace (changing the frequency after restarting the oscillator). The most significant factor to the quartz frequency stability is temperature. The design of the quartz affects the temperature dependance, which yields to different quartz characteristics (Fig 1).

2. 2. TIME-KEEPING

The issue of time-keeping is applicable to various areas of everyday life. Precise timing came with the invention of the quartz-crystal oscillator and quartz-crystal filters, which are essential elements for radio, radar and television with their enormous, far-reaching impact on our society (HP, 1997-2). Time synchronization is a key factor in distributed measurement systems (Carta et al, 2011). Wherever two or more queries arises in the same time at the same place, the two spots generating the queries have to record the same time tag. The time standard is available in different forms: as second pulses received from the specialized radio-stations, Geo-synchronized satellites, Internet, or directly by connecting low-cost GPS receivers to a computer, to discipline its quartz oscillator.

The easiest way to synchronize the time in the local area network (LAN) is, certainly, by Network Time Protocol (NTP). The synchronization is performed in two steps: installation of the necessary software (which is a freeware application available for different platforms) and selecting the NTP server of a higher priority (stratum). Although it looks like the most appropriate tool for clock synchronization, an extensive research of NTP features, in which more that 8100 NTP servers were included in the experiment, showed that 26% of NTP servers were more than 10 s off the UTC (Buchholz and Tjaden, 2007). Besides that, the offsets of the NTP discipline could significantly vary in time, which makes it quite unreliable for time-keeping in astronomy. NTP synchronization is a continual process and, due to that, not appro-

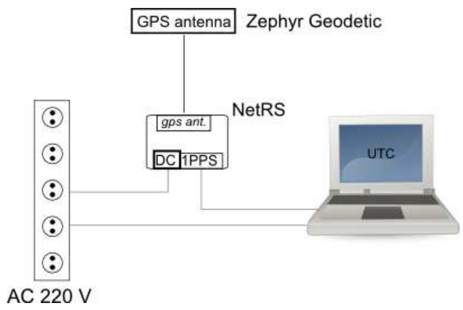

Figure 2: Experiment set-up.

priate for the offline applications, which need synchronization only from time to time (Hämälainen, et al, 2006).

2. 3. TRANSFER OF UTC TO A LAPTOP

Each time scale is characterized by a periodic signal that represents the time unit providing a universal temporal reference. The time scale is reliable in the extent to which that period is not subject to changes over time (Farina et al, 2009). The frequency of the oscillator is measured by comparing with the standard frequency (Balbuena et al, 2009). UTC pulses can be transferred from the GPS time standard using the 1 pulse-per-second (1PPS) feature of a GPS receiver (Schmid, 1994). The pulses are transferred to a laptop via a serial communication link (Pryke and Lloyd-Evans, 2000). In order to avoid the unnecessary latencies in receiving UTC second signals, we designed a low-level interrupt driven routine for catching the UTC ticks (Ogrizović, 2009). As a UTC standard we used a double frequency GPS receiver TRIMBLE NetRS, with the possibility of transmitting the 1PPS pulses with the resolution of 40 ns and, due to certain external factors, nominal accuracy of 1 μs (TRIMBLE, 2004). The accuracy of 1PPS transferred from the GPS receiver depends of the stability of the GPS receiver clock, which is tested comparing with the higher time standards, i.e., cesium or rubidium clocks (Weinbach and Schön, 2011).

For the purpose of the experiment, the routine is customized in the way that all other functionality, i.e. reaction to user input or processing of measuring data are disabled, only the time registration is left. UTC pulses are registered using two special processor registers. With the nominal frequency of the laptop's quartz oscillator of 133 MHz, the time resolution results to, approximately, $7 \cdot 10^{-9}$ s. The experiment set-up is presented in the Fig. 2

3. RESULTS AND DISCUSSION

3. 1. EXPERIMENT DESCRIPTION

We performed our measurements in two days, exposing the laptop to different ambient conditions. During the first day (experiment set-up #1), the laptop was exposed to constant ambient temperature of 16°C, which is close to the optimal temperature for that type of the quartz (HP, 1997-1). After removing the gross errors, caused by sudden cycle-slips during the data acquisition, the resulting graph of measured second pulses shows the behavior presented in the Fig. 3.

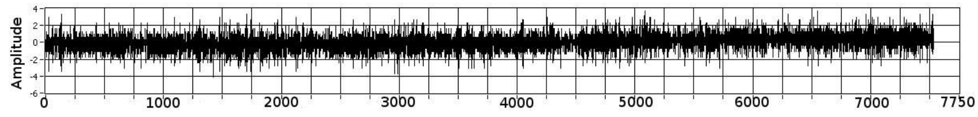

Figure 3: Set-up #1.

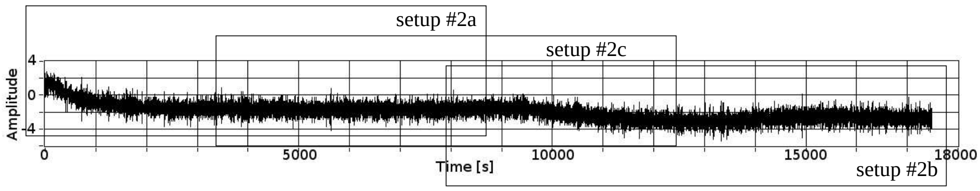

Figure 4: Set-ups #2.

The session #2 lasted for 5 hours. During the first 2,5 h the laptop was placed outdoors, at the ambient temperature of 0°C. After that, without turning it off or any waiting for the ambient accommodation of the device, the session is continued 2,5 h more indoor, at the temperature of 21°C. The graph of the complete session is shown in the Fig. 4. For the processing purposes, the session is split in three set-ups: set-up #2a, with outdoors measurements, set-up #2b, with indoors measurements, and the set-up #2c, that covers the period when the temperature drastically changes from 0°C to 21°C.

We calculated the clock characteristics (offset and bias) by assuming a linear trend of the clock bias (Ogrizović, 2009):

$$UTC_i = T_0 + (1 + b)\, T_i, \tag{1}$$

with:

- UTC_i - time events (1PPS) expressed in hours
- T_0 - clock drift,
- b - clock bias, and
- T_i - time events in cycles.

Time events in processor cycles are calculated using the two special registers, according to:

$$T_i = HB_i \cdot 2^{base} + LB_i, \tag{2}$$

with:

- HB_i - high priority word (byte),
- LB_i - low priority word (byte), and
- $base$ - the length of the basic word. In our experiment, the laptop owned a Pentium I class processor with 133 MHz nominal frequency, so $base = 32$, since this is a 32-bit processor.

Table 1: Calculated biases

Set-up #	T [°C]	b [s/h]	σ_b[s/h]
1	16	0,003	0,001
2a	0	-0,033	0,002
2b	20	0,006	0,002
2c	0-21	-0,026	0,003

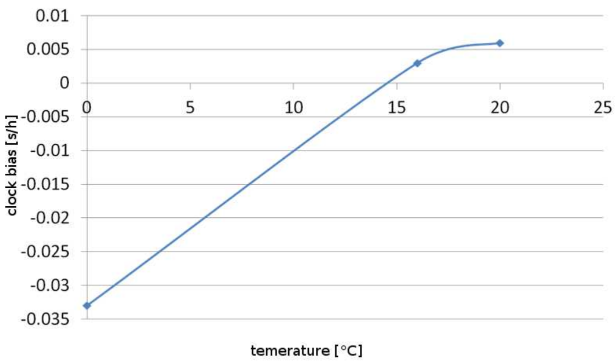

Figure 5: Bias dependence of the ambient temperature.

3. 2. RESULTS OF THE CALCULATED CLOCK BIAS

The offsets and biases are calculated for all four set-ups using a least squares method. The obtained biases with standard deviations are given in the Tab. 1. The accuracy is similar in all cases (0,001 - 0,003 s/h), which proves the stability of the measuring and calculating process. However, it is noticeable that the lower bias values correspond to the temperatures closer to the optimal value.

Graphically, the values of set-ups #1, #2a, and #2b show the increasing trend (Fig. 5), which corresponds to the theoretical models, depicted in the Fig. 1. The set-up #2c is treated separately. The value of the bias (-0,026) cannot be considered as constant throughout the measuring session, due to its dependance on the temperature. Such case is unlikely to experience in the practice, and it is given here just for approving the model used.

4. CONCLUSION AND REMARKS

The quartz oscillators show the significant dependence of the ambient temperature. Due to that, a special attention should be paid on using quartz driven clocks in outdoor measurements. The recommended method for time-keeping during the measuring sessions in field is by transferring UTC pulses from a GPS receiver to a laptop computer. Registration of time events should be recorded in the units of laptop's quartz oscillator clock using an interrupt routine, in order to avoid the latencies caused by the signal path from the GPS to the laptop.

The short-term stability of the quartz (several hours, during the measuring session) can be achieved by keeping the laptop indoor, possibly in the car, if the station where the measurements are performed is four-vehicle approachable. In other cases, a chamber for the laptop should be provided, with the indoor temperature that not changes more than 5°C during the session.

Finally, due to the aging of the quartz, which can change the oscillator characteristics and, accordingly, the frequency of the oscillator, periodically checks of the oscillator should be performed in the accredited laboratory for time and frequency calibration.

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